INDIRECT MEASUREMENTS OF ATMOSPHERIC TEMPERATURE PROFILES FROM SATELLITES: III. THE SPECTROMETERS AND EXPERIMENTS

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ABSTRACT

Three spectrometers and associated experiments are described. The work reviewed comprises the early experimental phases of a program to develop a satellite infrared spectrometer capable of making radiometric measurements in the 15-micron carbon dioxide band needed for deduction of atmospheric temperature profiles. Initially, a simplified, breadboard spectrometer with four spectral channels was used to determine the temperature profile of the lower atmosphere from the ground. Next, a commercial spectrophotometer was modified and another determination of the atmospheric temperature profile was made using more spectral intervals. Instrument specifications for a balloon flight model spectrometer were derived from these experiments. Following the model's fabrication, testing, and calibration, two high-altitude balloon flights were conducted to demonstrate that the atmospheric temperature profile could be ascertained from above the atmosphere.

1. INTRODUCTION

The discussion by Wark and Fleming in the first paper of this series was based largely on the use of a spectrometer to obtain the radiance measurements in the 15-micron carbon dioxide band. A spectrometer was selected as the most suitable instrument after several types of instruments were considered. It can easily isolate narrow spectral intervals, and can measure with the required accuracy the radiant energy in these intervals.

In this paper the authors will discuss the development of an instrument which is to be flown in a satellite, and three experiments carried out to test the instrumental feasibility and the application of measurements to temperature soundings by the techniques already discussed.

2. BREADBOARD SPECTROMETER EXPERIMENT

The first experiment, conducted at ground level, employed a laboratory breadboard model of the spectrometer. This instrument was constructed to test the design of a satellite instrument, and, secondarily, to conduct experiments from the gound to determine the temperature profile near the ground from zenith sky radiance measurements.

The spectrometer has been described by Dreyfus and Hilleary [3] and is shown in figure 1. The Barnes Engineering Company constructed a filter-grating spectrometer having an $f/5$ aperture, a 16-in. diameter spherical mirror with a 25-in. focal length, and a 5-in. square diffraction grating. The grating was ruled at Johns Hopkins University. Five exit slits were located above the grating position to isolate the radiant energy in the spectral intervals of interest; four intervals were in the 15-micron carbon dioxide band to conform to the original limited-concept experiment for temperature sounding, and the fifth was in the clearest part of the window region at 899 cm.$^{-1}$ The energy was detected behind each exit slit by a wedge-immersed thermistor bolometer described by Dreyfus [2]. Radiation entered two apertures, called "earth" and "space" ports, on opposite sides of the spectrometer's cylindrical housing. A chopper rotating at 15.4 c.p.s. alternately admitted radiant energy into the instrument from each port.

For the ground experiment, a blackbody reference source at 0° C. was used at the space port, and atmospheric radiation entered the earth port. The response of the instrument was checked occasionally by rotating a mirror within the instrument so that the earth port could view radiant energy coming from a blackbody cone mounted internally. The temperature of the cone was measured.

A separate detector collected energy in each spectral interval. Each detector employed its own preamplifier, but only a single electronics channel was used for signal processing thereafter. The preamplifier output for each spectral interval was switched into the processing electronics channel and recorded. A filter circuit set the time constant of the system at six seconds to reduce the noise fluctuations to the allowable limits. The response for each spectral interval was found to be a linear function of radiance when compared to the *difference* in the radiance

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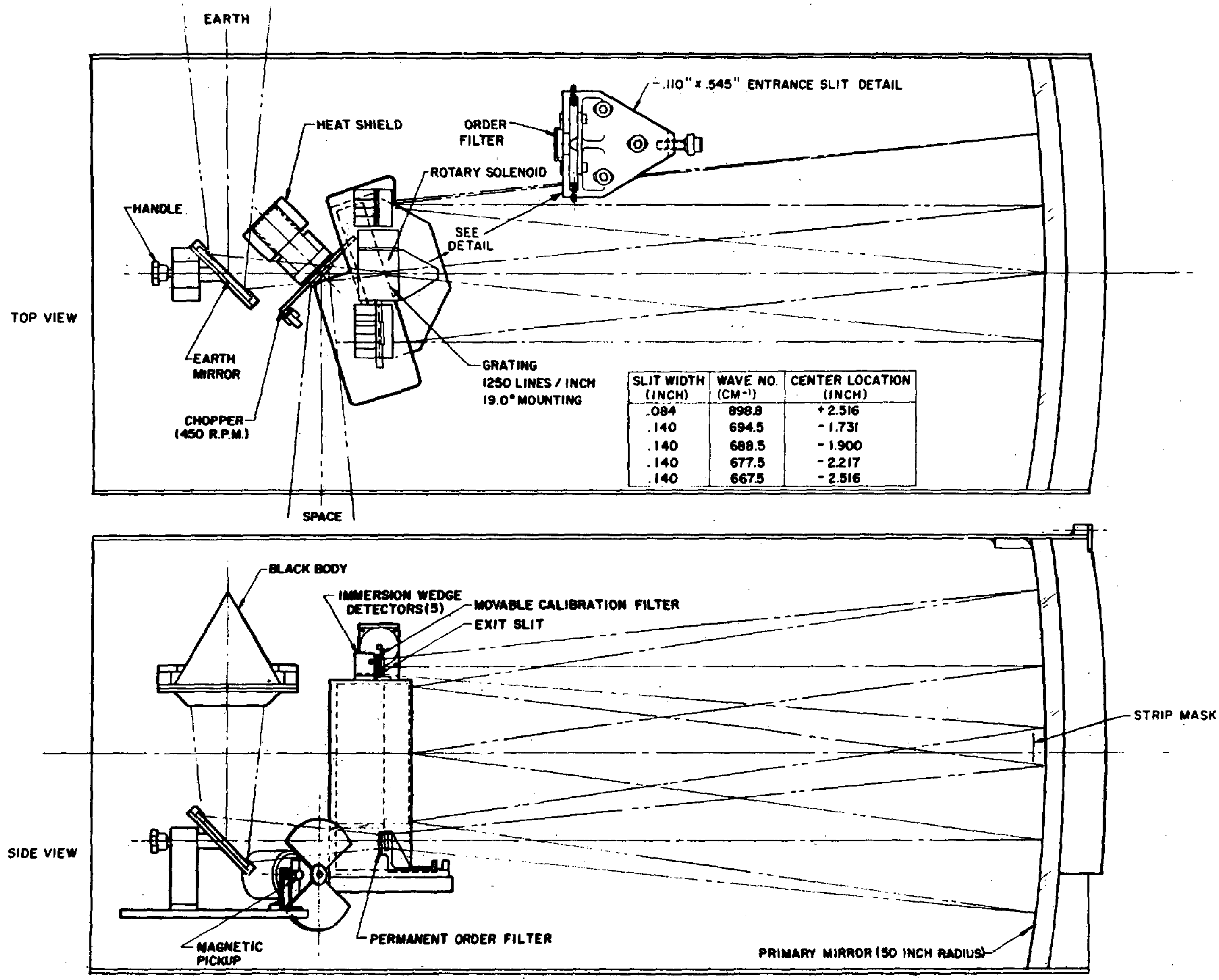

FIGURE 1.—Top and side view diagram of the satellite infrared spectrometer breadboard model.

between two external blackbody references operating at different temperatures. A zero reference was provided by installing a shutter which could be controlled externally to cover the entrance slit, as shown in figure 1. Although the temperature of the instrument did affect the responsivities of the thermistor flake detectors, the experimental procedure was adequate to determine the calibration.

The spectral intervals monitored during the experiment were centered at 667.5, 677.5, 688.5, and 694.5 cm.$^{-1}$ in the 15-micron carbon dioxide absorption band. Bandwidths for these spectral intervals were 4.55, 4.70, 4.90, and 5.00 cm.$^{-1}$, respectively, at the half-power sensitivity points. The band-pass functions were shown indirectly to be very nearly triangular and the wavelength calibration was adjusted to a few tenths of a wave number, using a mercury arc source to produce a higher order spectrum at the exit slits. The calibration was checked during the experiment by a specially designed interference filter.

The errors in measurement came predominantly from the random thermal noise in the detectors. To determine the magnitude of the errors, the signal from each spectral channel was sampled instantaneously 1000 times during a 6-hr. period in a laboratory free of extraneous electromagnetic radiation. The entrance slit was blocked during this period. Signal variations were found to have a root-mean-square value of about 0.25 erg/(sec. cm.^{2} strdn. cm.$^{-1}$). Such low noise levels were not achieved during the other experiments discussed here because interference from other electrical equipment and nearby microwave radio transmitters increased the experimental rms error to approximately 0.5 erg/(sec. cm.^{2} strdn. cm.$^{-1}$). This latter value is, however, within the limits set by Wark and Fleming.

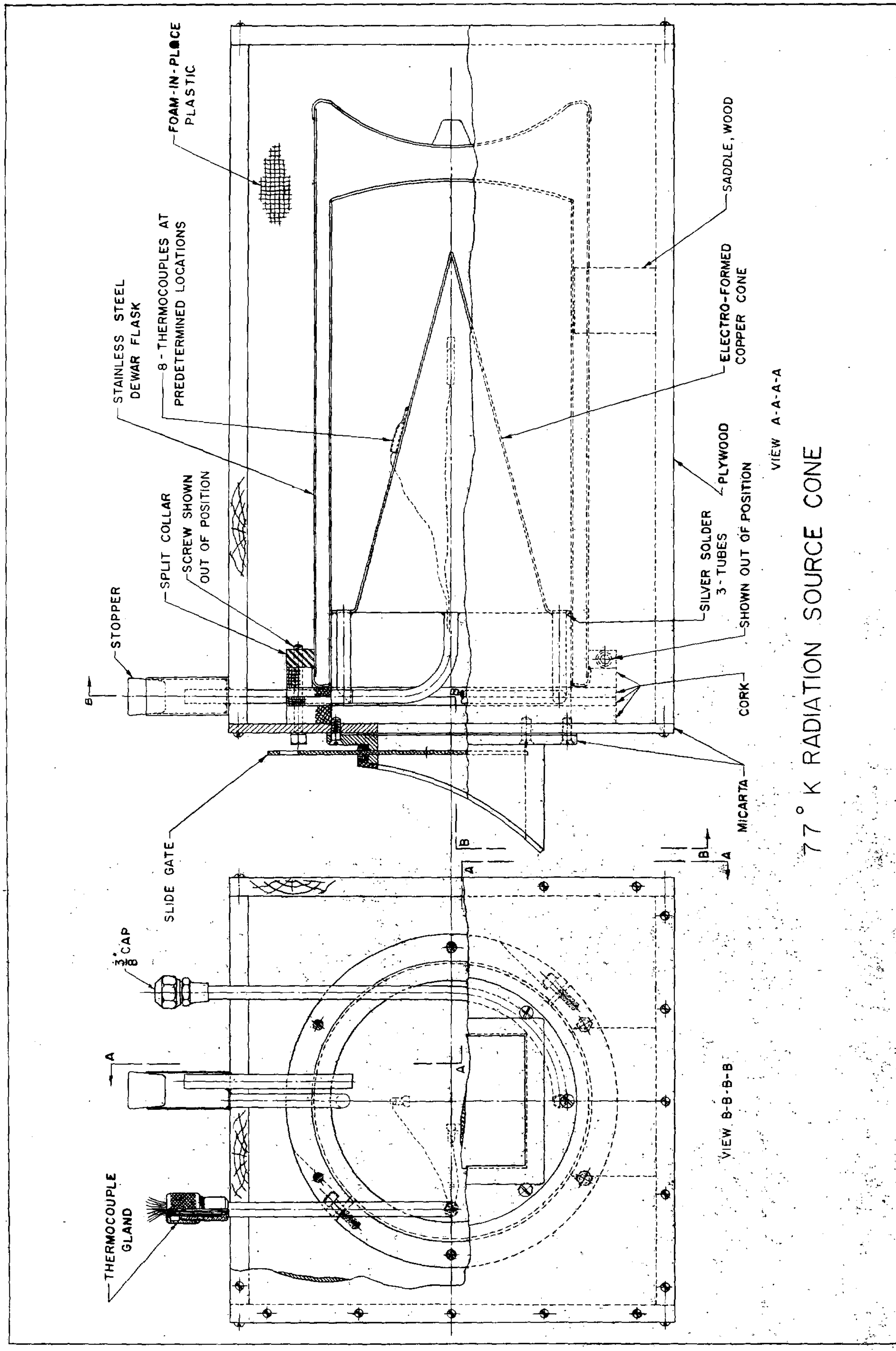

FIGURE 2.—Front and side view diagram of blackbody radiation cone.

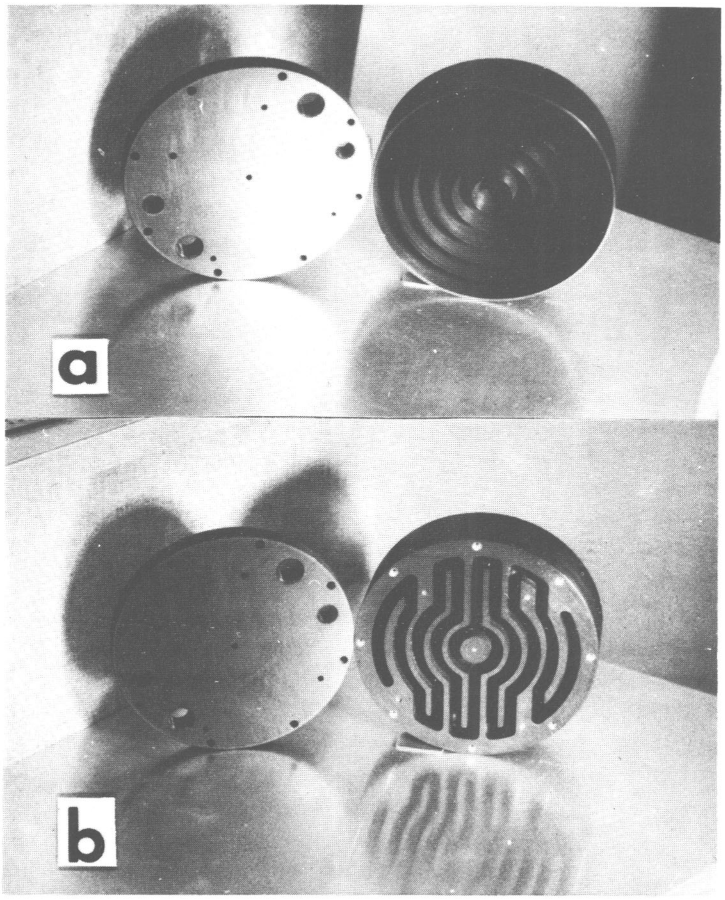

FIGURE 3.—Fresnel radiation cone showing (a) the front surface and (b) the heat transfer grooves at the back.

The cones used at the space port as a source of blackbody radiation had an apex angle of 30° and a diameter of 5¼ in. Each was made from ⅙ in. thick electroformed copper and had nine thermocouples distributed over the outside surface (see fig. 2). The cones were set into tanks, through which temperature-controlled liquids were circulated. The inside, or radiating, surface of the cones was painted with Parson's optical black lacquer, which had an infrared emissivity of about 98 percent. According to a formula of Gouffe [4], the cones had an effective emissivity of 99.8 percent. DeVos' [1] work showed Gouffe's formula to yield conservative values.

A Fresnel (folded) radiation cone was used at the "space" port of the breadboard spectrometer to allow the instrument to be tilted during use for convenience. The radiating surface consisted of six concentric, V-shaped grooves, each with an included angle of 22.5°. It was machined from aluminum with a labyrinth of heat transfer grooves milled into the back for the circulation of a liquid medium for temperature control, and the back was closed with a cover plate as shown in figure 3. Five thermocouples were inserted almost to the radiating surfaces from the back. The radiating face was painted with Parson's optical black lacquer and other surfaces were covered with sheet cork. The effective emissivity of the Fresnel cone as indicated by the spectrometer was within 1 percent of that of the conventional cones.

The breadboard spectrometer was purged continuously during the experiment and calibrations with dry nitrogen gas from liquid nitrogen containers at a rate of 70 ft.^{3}/hr. The gas escaped through the "earth" port. A plane, aluminized mirror deflected the atmospheric beam from the vertical into the "earth" port during measurements of sky radiance. The reflectance loss at this mirror, about 2 percent, was not compensated for by using a similar mirror in front of the external blackbody cone during the calibration checks. The indicated spectral radiance values were corrected by allowing for the mirror emission and the reflection losses. For a response check, the external source was moved into position to fill the optics of the spectrometer at the "earth" port. This allowed corrections to be made for changes in the response of the instrument and for absorption by any carbon dioxide gas remaining inside. The external cone was cooled initially to 0° C. by using an ice-water mixture. It was allowed to warm slowly to room temperature as the experiment progressed so that calibration data were obtained for a range of blackbody temperatures between measurements of sky radiances. The Fresnel cone at the "space" port was maintained at 0° C. during the experiment. The radiance of the internal cone varied slightly as the instrument warmed, and provided additional response data. Critical instrument temperatures were monitored continually on a thermocouple recorder, including those of the "space" blackbody, the internal reference cone, and the detectors.

Air temperatures were monitored near the optical path by shielded thermocouples at distances of 9, 18, and 50 ft. above the deflecting mirror. These provided an approximate temperature profile of the lower atmosphere for comparison with the calculated profile.

A very similar arrangement was used to measure radiances associated with an atmospheric temperature profile discontinuity. The apparatus was set up in an air-conditioned room during summer. The "earth" sensing beam of the spectrometer was directed through a window and elevated slightly to clear a nearby building. Thermocouples were used to determine air temperatures in the sensed beam within the room and outside the window, and a shielded thermistor mounted on a pole was used in the free air away from the building. The room was well chilled overnight and tropical air mass conditions prevailed outside. The results of this experiment are discussed by James in the fourth paper to be published in this series.

3. BECKMAN IR-7 SPECTROPHOTOMETER EXPERIMENT

The temperature profiling experiment was also performed on the ground with an IR spectrophotometer to test the use of spectral intervals in the wing of the carbon

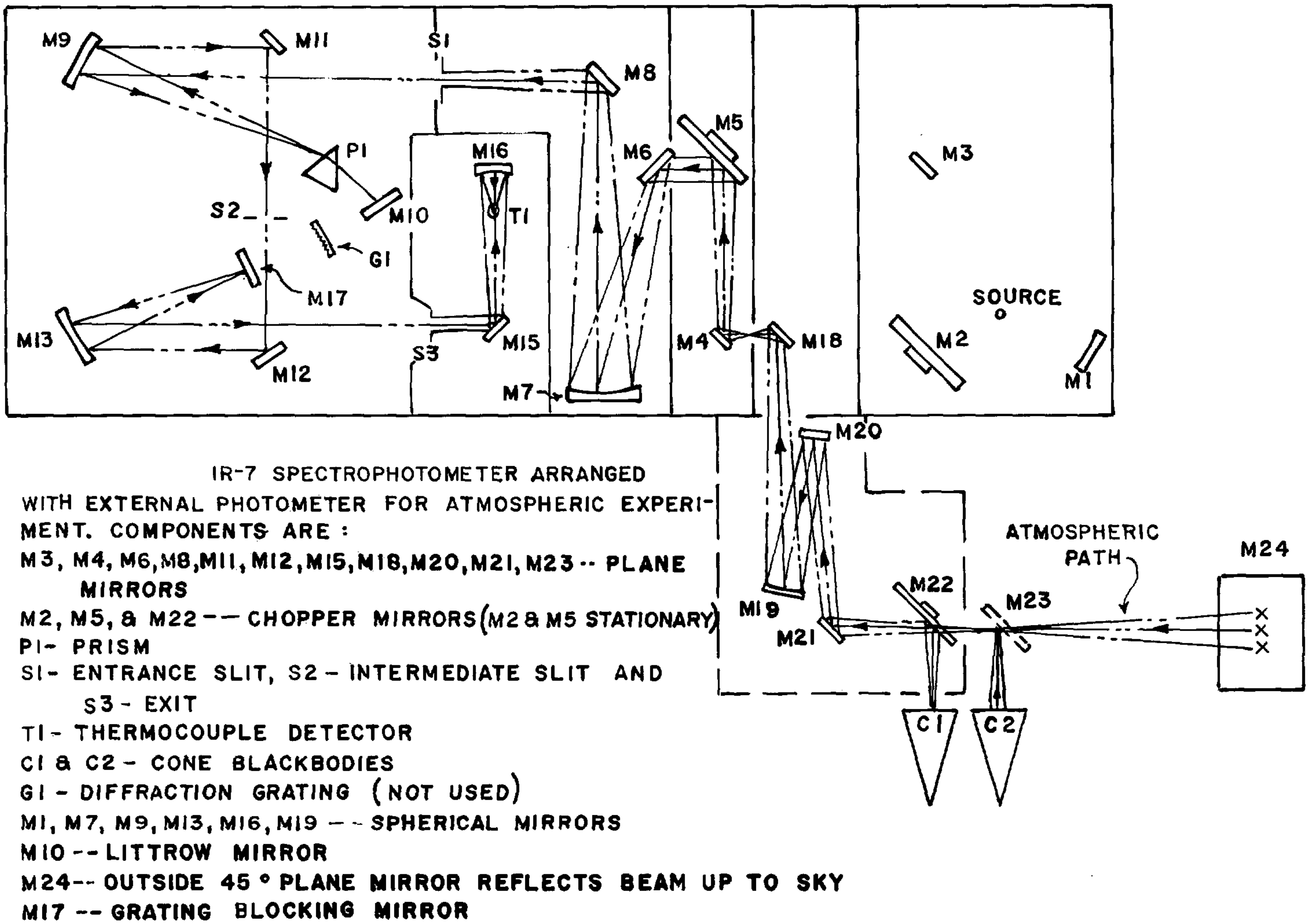

FIGURE 4.—Optical configuration of Beckman IR–7 spectrophotometer and external photometer arranged for atmospheric experiment.

dioxide band which were not measured by the breadboard instrument and to confirm independently the results of the breadboard instrument experiment.

This instrument is a prism-grating infrared spectrophotometer which has been tested and reported upon by Krueger [5]. It was used to determine the atmospheric temperature profile from the ground with more spectral intervals than monitored by the breadboard instrument. The manufacturer fitted the spectrophotometer with a removable mirror which, when placed before the grating, allowed wide spectral bandwidths to be attained. Here, the optics of the second monochromator simply placed the exit slit at the position of the intermediate slit which was kept somewhat wider. This mirror, M–17 in figure 4, must be aligned carefully to prevent occluding the exit slit with one of the intermediate slit jaws. The instrument was calibrated for wavelength in this configuration by detecting the individual carbon dioxide absorption lines using very narrow slits.

The spectrophotometer, so altered, functioned as a single prism monochromator. The stray radiation at 650 cm.$^{-1}$ was about 3 percent when operated with its Nernst glower source. Stray radiation during the experiment was negligible because the shorter infrared wavelength radiances of the atmosphere were much less than those of the Nernst glower source. Similarly, any contribution of diffuse solar sky radiation to the stray radiation was comparatively small. The instrument was operated in the single-beam energy recording mode. A rock salt prism [5] and a Beckman thermocouple detector with a cesium iodide window were used. The spectral resolution was adjusted to approximate that of the breadboard spectrometer.

Figure 4 is a plan view of the arrangement used for the experiment. The internal chopping mirror, M–5, was stationary. The chopping, synchronous rectification, and balance signal generation were performed with external Beckman IR–7 chopping mirror assemblies installed to avoid measurement of mirror emissions. When so modified the instrument measured the difference between the atmospheric radiation and that from a blackbody source, C–1. This configuration preserved the normal

$f/10$ aperture of the instrument with M–23 imaged near M–4 and at the entrance slit. An open-end enclosure was placed around the external optics and attached to the spectrophotometer's regular enclosure to permit purging with dry nitrogen gas of almost the entire optical path.

The blackbody sources, C–1 and C–2, were the same as those used with the breadboard spectrometer. An additional mirror, M–24, was used to deflect the atmospheric beam from the vertical to the horizontal to enter the external photometer (indicated by dashed outline) at M–22, the external chopper. C–1 is a blackbody source cone which was maintained at 0° C. ±0.2° C.

The response of the instrument was checked by inserting mirror M–23 into the path and directing the instrument's field of view into blackbody source C–2, which was cooled to −20° C. and then warmed to +25° C. The spectrophotometer was scanned through the region 660 to 750 cm.$^{-1}$ at each temperature.

4. BALLOON FLIGHT EXPERIMENT

After experience gained in the experiments described above, a contract was awarded to Barnes Engineering Company for development of three identical spectrometers equivalent optically to the breadboard instrument. One of these was used on a high-altitude balloon flight to test the feasibility of the satellite experiment. These spectrometers were identical to the breadboard model except as discussed below.

Figure 5 is a diagram of the balloon-flight model. A plane mirror has been added below the grating and the entrance slit has been relocated. The chopping and earth mirrors were made smaller and the chopper was driven by a rim gear. The earth beam was normal to the plane of the figure. Three solenoids controlled (1) the shutter to block the entrance slit, (2) the earth mirror, and (3) the calibration check filter used before the exit slits.

Several mechanical engineering problems were obviated and a reduction in weight was achieved by a new design of the main mirror. The mirror blank was cast of aluminum and its surface was machined, ground, and coated with a hard nickel phosphide surface which was then polished. An aluminum coat and a thin layer of silicon monoxide were applied in a vacuum. The 6-pound mirror was triangular in shape. At 25 in. the mirror produced a circle of confusion of about 0.009 in. This smeared the spectrum about 0.3 cm.$^{-1}$ at the exit slits. It was bolted to the cylindrical housing of the instrument and had nearly the same coefficient of expansion as the housing. The other mirrors, including the chopper, also were made of aluminum. The pyrex grating blank was the only glass component.

The balloon flight spectrometer was designed to measure radiation in six 5-cm.$^{-1}$ wide spectral intervals centered at 669.0, 677.5, 691.0, 703.0, and 709.0 cm.$^{-1}$, and in an 8.75-cm.$^{-1}$ wide spectral interval centered in the atmospheric window at 898.9 cm.$^{-1}$

The signals from the seven detectors were amplified

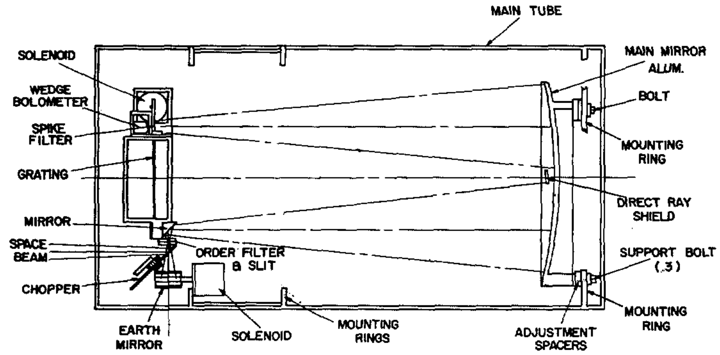

FIGURE 5.—Top view diagram of the infrared spectrometer model for balloon flights.

and processed in seven complete parallel electronic channels as shown in figure 6. The transistor preamplifier was developed by Barnes Engineering Company and modified for a negative power supply voltage and a 4-megohm input impedance. The noise of the preamplifier was 1.5 db. at a bandwidth of 160 c.p.s. Some temperature compensation for each channel was achieved with a thermistor mounted in the detector housing. Electrically, it was part of the feedback loop of the operational amplifier. The thermistor was shunted by a variable resistance used to adjust the slope of the temperature correction function. Figure 6 also shows the relative responses at various temperatures of the breadboard spectrometer and the balloon-flight model spectrometer.

The operational amplifiers used for the balloon-flight instrument were developed and produced by ESS GEE, Inc., White Plains, N.Y. They were designed for this spectrometer and also to be compatible with the Nimbus weather satellite system.

The synchronous demodulators were redesigned for the balloon flight. The circuits for the six carbon dioxide interval channels were equipped with relays to select one of three synchronous clamp reference voltages in order to provide three calibrated input ranges. The output voltage changed from 0 to −5 volts as the radiation signal varied from −5 to 55, 20 to 80, and 95 to 155 ergs/(sec. cm.^{2} strdn. cm.$^{-1}$) on the low, middle, and high ranges, respectively. During the balloon flights the low range was used only for the zero signal check and the high range only for the internal reference cone calibration check. All the earth radiances were measured on the middle range. It was possible to program the range changes as part of the calibration sequence while the solenoid controlling the zero block shutter, earth mirror, and wavelength calibration filter were operated. The range offsets were checked during the flight with test signals inserted at the output of the operational amplifier.

The instrument was equipped for the flight with a cold blackbody radiation source designed by Barnes Engineering Company and Linde Division of Union Carbide Corporation. It was clamped over the "space" port of the

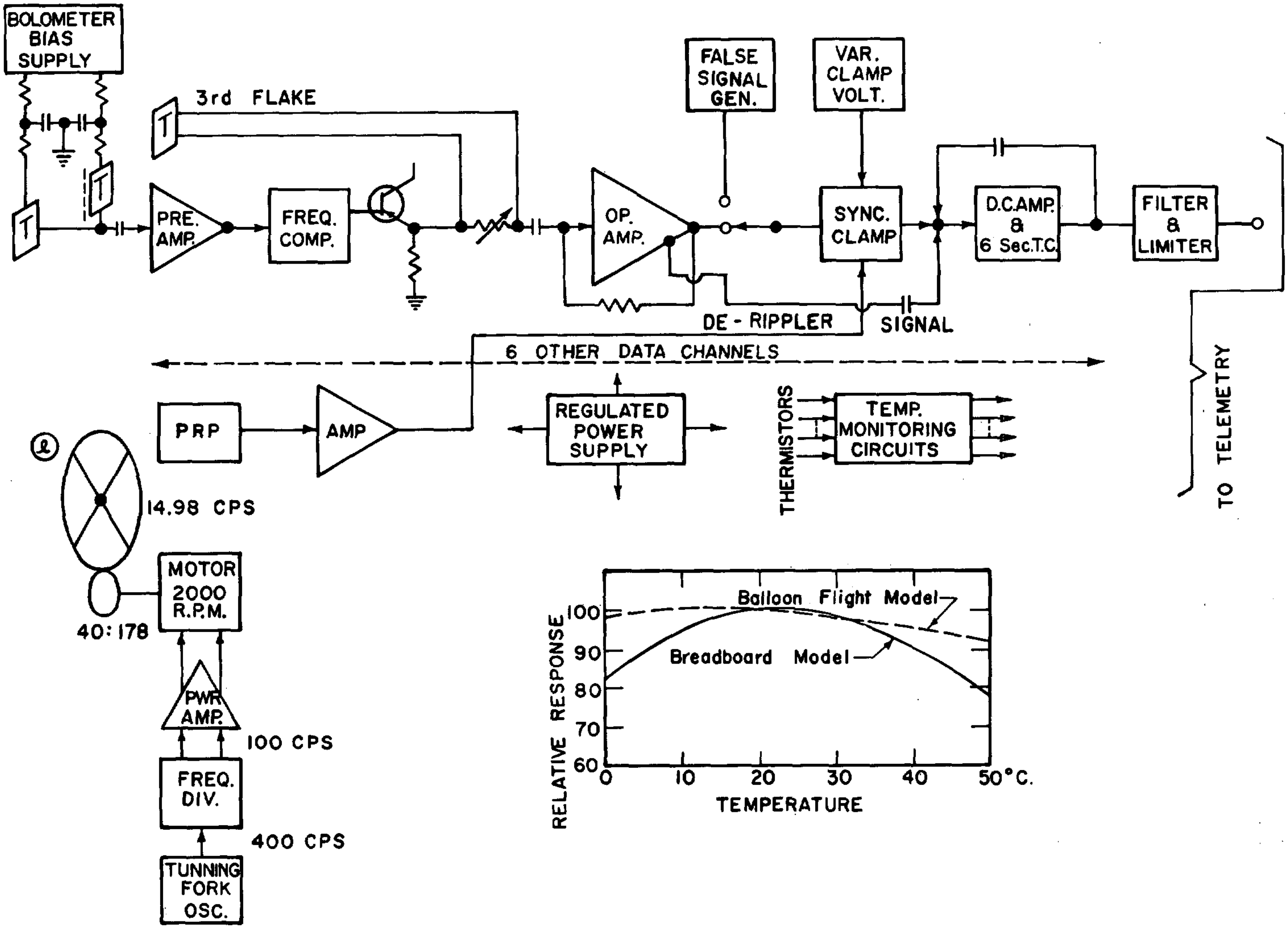

FIGURE 6.—Block diagram of electronic and temperature compensation networks. The relative response for various temperatures of the breadboard spectrometer and balloon flight spectrometer.

spectrometer to serve as a zero reference. It consisted of a blackbody source cone set into a Dewar container filled with liquid nitrogen. The dry nitrogen gas passed through a pressure relief valve and purged the face of the cone and the instrument as the liquid nitrogen evaporated.

The spectrometer was fitted with a door over the "earth" port to maintain the nitrogen gas purge during the ascent of the balloon. The door was opened by a baroswitch at a predetermined altitude.

Two identical spectrometers were prepared and calibrated for the balloon flight. Serious trouble developed in one spectrometer a few days before the flight when water vapor condensed in the detectors.

The response of the second spectrometer was calibrated five times with 0° C. and twice with −196° C. blackbody sources at the "space" port. A blackbody source cone whose temperature was controlled by circulating freon cooled by dry ice was used in the "earth" beam when the −196° C. blackbody source cone was used in the "space" beam. The calibrations performed with the −196° C. blackbody source cones were not very precise. However, they did serve to show that the five other calibrations were applicable to the balloon-flight conditions and they tested the radiative balance of the chopping system. The balance was tested also by using two −196° C. blackbody source cones. Some imbalance was detected initially but this was eliminated by cleaning the earth and chopper mirrors.

The attenuation in each channel caused by the calibration filter was determined at various instrument temperatures because the spectral transmission of the filter changed slightly with temperature. The spectrometer was tested for its sensitivity to reflected solar radiation by using a 1000° C. blackbody source and a lamp source with Irtan-1 and glass plates, respectively, to block the radiation at 15 microns.

The detector variation of response with temperature was compensated for by making circuit adjustments until the output signal, at a constant blackbody temperature, changed less than 2 percent when the detector temperature was cycled between 8° C. and 30° C. using thermoelectric cooler modules. Each electronic circuit board was tested in a temperature chamber for stability between 0° C. and 40° C. The instruments were tested for stability with battery voltage changes of ±3 volts.

The first balloon flight was conducted by the National Center for Atmospheric Research (NCAR) from the National Scientific Balloon Flight Station at Palestine, Tex. The balloon chosen for the flight had a volume of 3.2×10^6 ft.^{3} It was made of GT–11 mylar-dacron scrim and manufactured by G. T. Schjeldahl Company. The gondola and ancillary equipment were designed and constructed by Vitro Laboratories, Silver Spring, Md. and consisted of a rectangular framework of welded aluminum with a plywood floor measuring 5 × 7 ft. All major components were housed in separate 4-in. thick polyurethane sheet foam boxes to provide thermal insulation. The equipment was packaged in five boxes: (1) the spectrometer, the blackbody source cooled by liquid nitrogen, and a 16-mm. camera; (2) two 12-volt, 35 ampere-hour, lead-acid batteries to provide power for the spectrometer heaters and the control programer; (3) the telemetry system and transmitter; (4) the batteries for providing power to the spectrometer, and (5) the balloon control equipment. Balloon control equipment included an altitude transmitter and tracking beacon, a photobarograph, a command receiver for ballast weight control and for detonation of a squib to separate the balloon from the parachute and gondola, a backup timer for squib detonation, and a rawinsonde transmitter.

The control programer was used to provide an in-flight calibration of the spectrometer every half hour. The calibration sequence began by inserting the beam blocker to check the instrument output with no signal. False electronic signals were inserted next to check the offset voltages of the low, middle, and high ranges. The beam blocker was then removed and the earth mirror positioned so the instrument could view an internal blackbody source cone whose temperature was monitored. Finally, a calibration filter was inserted in the beam to check for wavelength shift in the channels. The calibration sequence required 6 minutes.

Two redundant baroswitches were used to open the earth port door at 90,000 ft. Information was telemetered to the ground with a 3-watt phase-modulated transmitter operating at 233.4 mc./sec. A cloverleaf antenna with reflector was suspended below the gondola. The transmitter, built by Vector Manufacturing Company, was used with the NCAR digital telemetry and command system. This system can accept 41 analog channels with input voltages from 0 to +100 volts and digitally encode them in pulse-code-modulation format to an accuracy of 0.2 percent at a sampling rate of two channels per second.

The telemetry signals received at the ground station were fed simultaneously into a tape recorder and a telemetry decoder. A Friden Flexowriter accepted the decoder output and printed the information for immediate inspection. A punched paper tape of the data was made at the same time for later use in a computer.

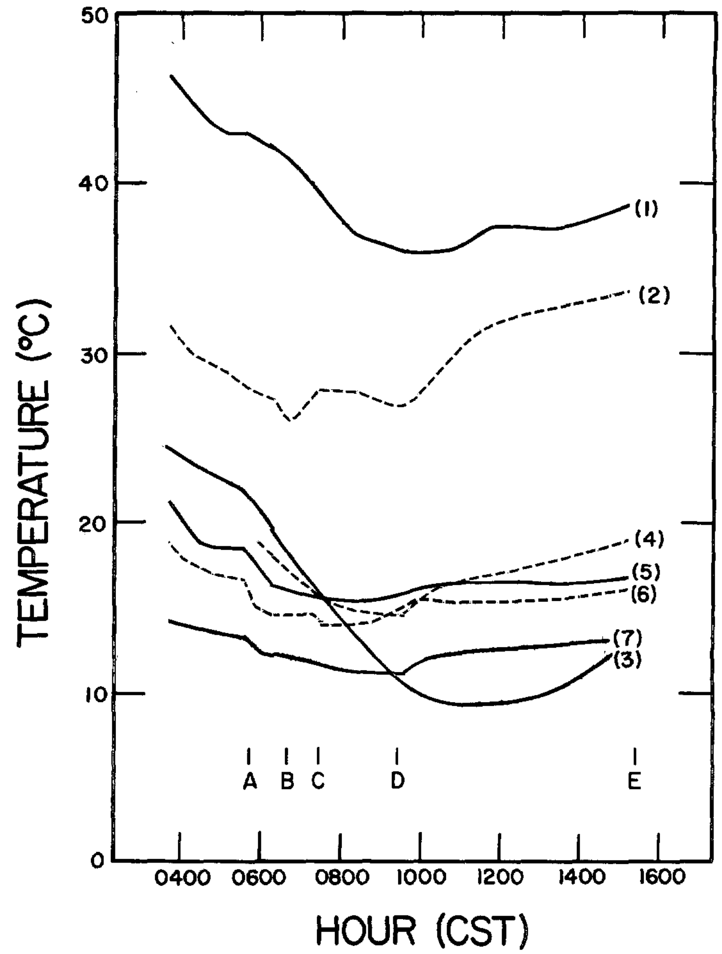

Figure 7.—Temperatures of infrared spectrometer components monitored during the September 11, 1964 balloon flight. The components are (1) power supply, (2) synchronous demodulators, (3) primary mirror, (4) detectors, (5) blackbody reference cone, (6) chopper and (7) order filter. Event times are (A) balloon launched, (B) thermostated heater turned on, (C) viewing port door opened, (D) heater turned on by radio command signal, and (E) flight terminated.

The NCAR digital telemetry and command system provides 20 command channels. If the control programer had failed, the calibration sequencer would have been disconnected and the individual calibration steps could have been performed by radio command. The command system was employed also to provide time marks for the film in the 16-mm. camera and photobarograph, to control an auxiliary heater in the spectrometer, and to open the earth port door as an alternate to the baroswitches.

Two environmental tests of the spectrometer and the liquid nitrogen blackbody source were performed before the balloon flight. The first test, conducted by the University of Michigan, was performed in an altitude chamber operated by Chrysler Corporation with infrared lamps to simulate solar radiation. This test indicated a possible spectrometer overheating and a metal strap was installed between the main casting of the spectrometer and the edge of the cold blackbody source to provide cooling by heat conduction. The second test was performed in an altitude chamber operated by the Westinghouse Corporation without simulating solar radiation and excessive cooling was noted. The thermostated heaters installed in the spectrometer to dissipate as much as 40 watts were evidently not adequate. A new, 20-watt heater, controlled by command, was installed. During the flight, seven critical instrument temperatures and eight voltages were telemetered to the ground and the spectrometer temperature stabilized near 15° C. with all of the heaters in use. Figure 7 shows the temperatures measured at various points in the spectrometer during the flight.

It was desired to measure the air temperature during the ascent of the balloon and at the float altitude of 100,000 ft. to an accuracy of 1° C. Precautions, suggested by Ney et al. [6], were taken to minimize the effects of infrared thermal radiation from the gondola and the earth and from solar radiation on the air temperature sensor at high altitudes. The sensors were quartz coated bead thermistors 0.014 in. in diameter.

An overcoat of aluminum was placed on the quartz coating to present a highly reflective surface to infrared and solar radiation. Two such thermistors were calibrated and flown. Each thermistor, supported by its 1-mil platinum leads, was mounted at the end of a thin, 6-ft. boom made of white polyethylene. The two booms extended horizontally in the same direction from adjacent lower corners of the gondola.

A regular Weather Bureau rawinsonde thermistor was carried also. It was mounted on a boom with one of the bead thermistors and used with a rawinsonde transmitter. The rawinsonde thermistor was used during the balloon ascent and at the float altitude until 1220 CST when trouble developed in the rawinsonde receiver. The fine bead thermistors were energized only after the balloon had reached 45,000 ft. where the air temperature was low enough to produce a high resistance in the thermistors in order to avoid excessive power dissipations in the fine beads. Both of the bead thermistors operated well until the parachute descent of the gondola began. Telemetry records from each thermistor indicated that they opened at this time, an indication that damage may have occurred during the freefall of the gondola or when the parachute opened.

Several of the 15-micron carbon dioxide band detectors in the spectrometer collected energy from the tropospheric region where clouds were likely to occur. Another spectral channel centered at 11.1 microns received its energy from the earth's surface or from cloud tops. Two 16-mm. movie cameras were mounted on the gondola to take time-lapse pictures of the earth and clouds so that data collected during the flight could be interpreted correctly.

A Siemens 16-mm. camera, Model B, was mounted in the insulated housing containing the spectrometer where the temperature remained sufficiently high to permit normal operation of the camera. It used a wide-angle, *f*/1.8 Switar lens with a 16-mm. focal length to provide a field of view greater than that of the spectrometer. An electronic timer pulsed the film advance mechanism exposing two frames per minute. The film magazine contained 60 ft. of Kodak Ektachrome ER Film on 2.5-mil Estar thin base. The film speed rating was ASA 64. The lens aperture was set at *f*/22 and the shutter speed was 1/50 sec. Good exposures were obtained with these settings except during the early morning when the low sun angle resulted in low scene brightness.

A second camera was loaned for the flight by A. D. Little, Inc., Cambridge, Mass. This 16-mm. Kodak Cine camera, Model E, had been used by Vonnegut and Atkinson [7] on other high-altitude balloon flights. It was enclosed in an insulated box and was attached to the side of the gondola. A d.c. motor continuously drove the camera mechanism exposing film at a rate of 7.6 frames per minute. Each frame was exposed for 2¾ sec. with the light level being reduced sufficiently by a neutral density filter mounted in front of the lens. The *f*/2.2 lens, with a focal length of 9.5 mm., had a wider field of view than the Siemens camera lens. The camera contained 150 ft. of Ektachrome ER film. Flight film exposures appeared to be about one stop less than those from the Siemens camera.

A radiometer for measuring the total hemispherical outgoing and incoming radiative flux from the atmosphere was attached to a boom on the gondola. These infrared data were collected during the flight for Dr. P. M. Kuhn at the University of Wisconsin.

Efforts were directed toward preparing the spectrometer for a September 11, 1964 flight. The weather forecast for this date was favorable and prelaunch preparations began on September 10, 1964. A down-range telemetry recording station was established at Brownwood, Tex., which is 200 mi. west of the Balloon Flight Station.

On the morning of the flight, launch crews arrived at 0130 CST. Four pilot weather balloons were inflated, helium gas was metered, and the parachute was attached to the launch truck. Vehicles supporting the operation were positioned on the launch pad. At 0230 CST a final check on the spectrometer was made before the gondola was attached to the launch truck and moved to the launch site. A final weather briefing at 0245 CST indicated the float altitude winds at 100,000 ft. were easterly at about 25 kt. and the flight was predicted to terminate west of Brownwood, Tex. The entire spectrometer system had been checked and left operating on its flight batteries two hours before the balloon was launched. The operation of all the systems was monitored by telemetry during the pre-flight preparations.

With everything functioning normally at 0400 CST, the inflation of the balloon with helium gas began. Liquid nitrogen in the blackbody cone was replenished at 0530 CST and 10 minutes later the balloon inflation was finished.

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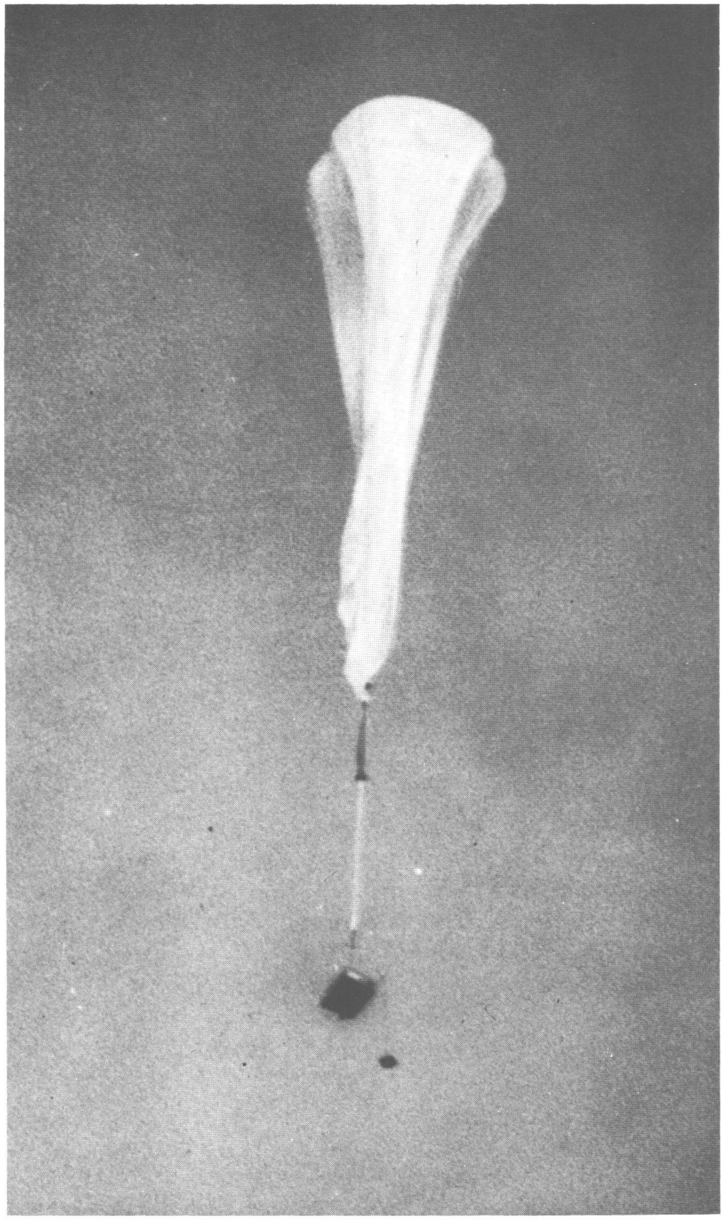

FIGURE 8.—Balloon ascent shortly after launching. A parachute connects the gondola to the balloon and an antenna reflector hangs from the gondola.

Pilot balloons released periodically indicated a very light westerly wind. All pre-launch activities were completed on schedule and a dynamic launch was performed expertly by the NCAR launch team at 0556 CST, several minutes before sunrise. Figure 8 shows the balloon and gondola during ascent.

Ballast was released periodically to maintain an ascent rate of about 1000 ft./min. The balloon reached its float altitude of 100,000 ft. at 0740 CST. The door covering the entrance port of the spectrometer opened automatically at 90,000 ft. and telemetered data indicated all equipment to be functioning. A few altocumulus clouds drifted into the area from the east during the ascent, but when the balloon entered the stratosphere, easterly winds carried it over a clear area after 0830 CST.

The NCAR Cessna 310 aircraft and two trucks carrying a recovery team left the balloon base shortly after the launch to follow the flight of the balloon during the day. Another team of three men followed the balloon by automobile and made radiation temperature measurements at the surface of the ground along the flight track. An aircraft from the Colorado State University flew at altitudes from 1,700 to 12,500 ft. beneath the balloon and measured the outgoing infrared radiation in the atmospheric window with two Barnes Engineering Company IT–2 radiometers.

The balloon passed near Waco, Tex. at 1100 CST and the weather began to change rapidly. Cumulus clouds built quickly into cumulus congestus and cumulonimbus along a cold front. While over the thunderstorm area, the balloon descended to the 12-mb. level and then rose later to 9.6 mb. over a warm, clear region west of the thunderstorms. More than seven hours of telemetered data had been recorded by mid-afternoon and the decision was made to terminate the flight at 1510 CST in an area of clear weather and over terrain accessible to the recovery crew. The parachute and gondola were separated from the balloon by a radio command from the tracking aircraft three miles south of Bangs, Tex. The parachute descent was normal and the impact with the ground occurred at 1604 CST about seven miles southwest of Brownwood. The recovery crew was able to arrive at the impact site within 10 min. and found the payload in a small clearing surrounded by mesquite. The gondola had been dragged 45 ft. on the ground before coming to rest on its side. The spectrometer was still operating and the other instruments were undamaged. Only the air temperature sensor booms and the gondola framework were damaged.

The spectrometer was recovered from the gondola in good condition after the flight and it was calibrated again the following day. The earth and chopper mirrors showed water marks from condensation which evidently occurred during the parachute descent of the gondola. The calibration slopes of the channels were several percent less than that determined before the flight. Cleaning the mirrors restored the slopes to their original values.

The 669-cm.$^{-1}$ channel flight data recorded when the spectrometer was viewing the internal reference cone proved to be in error. Postflight calibration showed a serious nonlinearity of its calibration curve for radiances greater than 115 ergs/(sec. cm.^{2} strdn. cm.$^{-1}$). An examination of the spectrometer revealed signal clipping in the operational amplifier. It was found that a potentiometer setting had changed which controlled the internal bias level in the amplifier. The clipping effect prevented inflight calibration of the 669-cm.$^{-1}$ channel data. Those data were not used in determining the vertical temperature profile of the atmosphere as discussed by Wark, James, and Saiedy in the sixth paper to be published in this series.

A second balloon flight of the infrared spectrometer was performed at Sioux Falls, S. Dak. in March 1965 in cooperation with the High Altitude Engineering Laboratory at the University of Michigan and the National Aeronautics and Space Administration. Unfortunately, a beacon radio transmitter on the gondola interfered with the spectrometer's sensitive electronics and most of the data from the 15-micron wavelength spectral channels were not usable for determining the atmospheric profiles.

5. SUMMARY

A program for development of an infrared spectrometer for measuring radiant energy in the 15-micron carbon dioxide band has progressed from a relatively simple breadboard instrument to the production of a much more sophisticated model which can be flown on a spacecraft. The breadboard spectrometer, utilizing four spectral intervals, was used on the ground to deduce the atmospheric temperature profile (see James' paper IV of this series, in preparation) from measurements of the zenith sky radiance. A special thermistor detector immersed on a wedge-shaped lens of germanium was invented to achieve sufficient performance.

A second experiment was undertaken which used eight spectral intervals instead of four to determine the atmospheric temperature profile from the ground. To accomplish this, a Beckman IR-7 spectrophotometer was modified to receive sky radiation. Again, the temperature profile was deduced (see Wolk, Yamamoto, and Van Cleef, paper V of this series, in preparation) from the energy measurements validating the sounding technique that was used in the initial experiment with the breadboard spectrometer.

Following this experiment, three spectrometers were developed. They were equivalent optically to the breadboard instrument and met the design requirements of a weather satellite system. One of these spectrometers was flown at 100,000 ft. on a high-altitude balloon in Texas in September 1964 to test its performance and to measure the spectral radiances necessary for computing the temperature profile. This flight was successful. In March 1965 another balloon flight was conducted in South Dakota in a polar air mass. Many of the data acquired during this flight were not usable because a radio transmitter interfered with the spectrometer's sensitive electronics. The results of these flights are described by Wark, James, and Saiedy in paper VI of this series, in preparation.

Satellite prototype and flight model spectrometers are now being produced under National Aeronautics and Space Administration sponsorship.

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The Sioux Falls balloon flight was conducted by the High Altitude Engineering Laboratory of the University of Michigan. The Raven Industries provided the ballon flight services and Vitro Laboratories personnel assisted in the spectrometer experiment.

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